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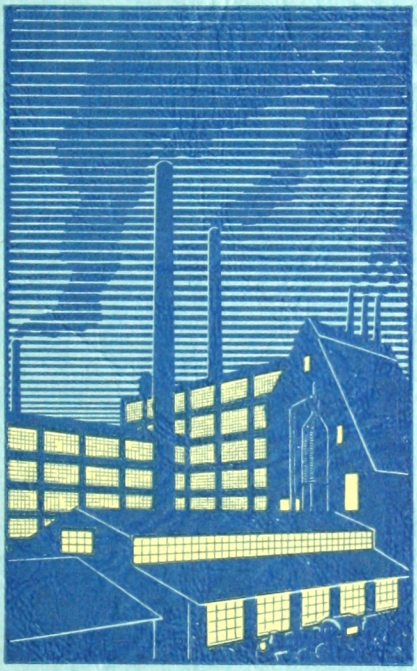
SPECIAL LIGHTING APPLICATIONS FOR INDUSTRIAL PROCESSES



INCANDESCENT LAMP DEPARTMENT
GENERAL ELECTRIC COMPANY
NELA PARK ENGINEERING DEPARTMENT
CLEVELAND

SPECIAL LIGHTING APPLICATIONS *for* INDUSTRIAL PROCESSES

by

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Special Lighting Applications for Industrial Processes

By JAMES M. KETCH, WALTER STURROCK and KARL STALEY

This paper discusses several lighting installations where special design features were necessary in order to meet the requirements. These special applications deal particularly with inspection processes that are found in industrial plants where unusual visual tasks are encountered. Ten lighting principles which have specific application to these problems have been classified and, where possible, illustrated with photographs of actual installations.

ARTIFICIAL lighting is commonly considered as being necessary for interiors and exteriors at times when daylight is insufficient and, in general, when designing an artificial lighting system, daylight is thought of as the ideal. In a well-planned system an attempt is made to duplicate it as closely as may be required in quantity, quality and color. For designing these artificial lighting systems a fairly well-established procedure is now in common use.

In some instances, however, where unusual visual tasks are encountered, it is necessary to design special equipments for those specific applications. Experience with such applications has demonstrated that artificial lighting can readily be controlled in quantity, quality and color and that it not only becomes more practical than daylight but also accomplishes results unobtainable from natural lighting. Particularly is this true where a directional beam, or a series of them, is required, or where a constant level of a given spectral quality of illumination must be maintained.

Proper artificial lighting for industrial processes is an essential, primarily from the standpoint of permitting careful inspection of manufactured products. For different classes of products the problems of inspection vary and, accordingly, the lighting requirements vary. To meet these requirements the value, flexibility and general adaptability of artificial illumination are well recognized, particularly

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in view of the availability of a broad line of equipments which make it possible to obtain almost any desired type of light distribution, diffusion, and quality. Modern artificial illumination is very versatile and truly the tool of the inspectors and production engineers.

The usual applications of artificial light to problems of inspection have, however, been made largely by raising the foot-candles of illumination with the increasing difficulty of the visual task. There is also a general feeling that if an existing lighting system is inadequate for the job, or that the flaws are not easily seen, the solution is to change the reflecting equipment, or to obtain more diffusion. The value of greater diffusion as it affects the ability to see details, reduce eye fatigue, and soften shadows is well known and, in general, its attainment is worth while. However, in the inspection field there are several other characteristics that are found to be equally as valuable as high levels and diffusion.

The visual tasks of modern inspection are so many and diverse, and the best methods of using artificial light to satisfy those requirements are likewise so numerous, and in some cases unusual, that it has been considered a worthwhile objective of this paper to classify the more important lighting methods, and to explain their applications to several difficult visual tasks.

Recognizing the various properties of both reflected and transmitted light, or radiant energy, the authors have enumerated ten principles for using them. These principles cover foot-candles, color, quality, diffusion, direction, etc., as related to general classes of flaws, defects, and imperfections.

CLASSIFICATION OF LIGHTING PRINCIPLES

(1) Illumination Level:

Seeing is a function of four factors: the brightness of the object seen; the contrast between any detail and its background, or any object and its surroundings; the size of the detail; and the time available, or necessary, for seeing. These factors are significant in the problems of inspection encountered in many industries today. Some of the problems are caused by the relatively low reflection factors of the materials used; some are contrast difficulties, such as scratch marks on relatively dark surfaces; in many industries size is important and would include the precision necessary for small parts assembly and for other delicate mechanical adjustments. With regard to the element of time, the workman may either have to meet the speed set

by a progressive assembly or machining process, or he may be working independently and be able to determine for himself the time necessary for a given operation. However, when time can be saved for any visual task by controlling the lighting, the benefits accrue to both employer and employee. The one obtains a greater production for each dollar spent; the other benefits in a conservation of nervous energy spent in the day's work. These factors are explained in more detail in papers by Luckiesh and Moss.[1] They have shown that in general the relation between foot-candles and benefits in seeing is logarithmic, so that a table based upon approximately equal steps of foot-candle effectiveness would show the steps increasing logarithmically in which the foot-candle intensity of each step is approximately double that of the previous one.

A foot-candle table arranged on this basis includes intensities that are much higher than those now in general use. And while such levels may seem impracticable, they can be easily and economically obtained by general lighting of a medium intensity supplemented by auxiliary lighting units located and directed to cover smaller areas.

The principles of lighting design are those commonly employed for the design of general lighting systems which give special attention to the spacing and mounting height of the luminaires, and to the selection of the type of reflecting equipment.

In general, good diffusion, and a reasonably even illumination on the work, as effected by the spacing-mounting height ratio, is desirable. Some jobs require a very high degree of diffusion, such as can be obtained only by special luminaire design; others will require no more than that obtained from standard commercial reflectors. The amount of diffusion and brightness of the luminaire that are desirable for the inspection of highly polished objects depends upon the area of the object. For small objects, such as needles, a clear lamp in an open reflector would furnish proper diffusion; for inspecting polished objects the size of razor blades and roller bearings a greater diffusion, such as would be produced by frosted lamps or stippled cover plates, would suffice; objects up to a foot in diameter should have brightnesses no greater than that of white bowl lamps in open reflectors, or glassteel diffusers; larger areas, such as tin plate, sheet aluminum, etc. that require the reflection of the luminaire brightness over a comparatively large area should employ special equipments for obtaining large areas of low brightness.

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[1] *Trans. I. E. S.*, Vol. XXV, Pages 15 and 807, and Vol. XXVI, page 1061.

Fig. 2 illustrates the lighting system in a plant manufacturing polished plate. The lighting units are of a special design to provide a low-brightness source for reflecting in the surfaces of the polished plate. These units are made of aluminum and are trough-shaped, as shown in Fig. 3. Each is equipped with five 750-watt lamps. The bottom of each unit is covered with ordinary white tracing paper to highly diffuse the light and eliminate the hazard which would be present if diffusing glass were used. Each unit is 10 feet long and 3 feet wide, and is mounted 42 feet above the floor. To facilitate lamp renewals, the units are suspended on disconnecting hangers for raising and lowering, and the individual lamp sockets are installed on small removable discs.

The applications of high-intensity lighting are many and include the inspecting of practically all types of objects for accuracy of machining, shape, contour, form, location, assembly, adjustment, size and contrast.

Fig. 4 illustrates an application of high-intensity lighting from luminaires located and directed to permit the delicate adjustment and inspection of armature type relays. The small relays are mounted, ten in a group, on frames 24 inches long. A trough-type lighting unit, 30 inches long and $6\frac{1}{2}$ inches wide, gives excellent distribution of light over the entire length of the frame. Each unit is equipped with four 50-watt Mazda lamps and a white diffusing glass cover plate.

(2) Color and Spectral Quality of Light:

The appearance of a colored object is influenced by the spectral quality of the illumination under which it is viewed. Accordingly, certain inspection processes that include the matching of colors require a careful selection of the light source as regards its spectral quality.

Much weight has been given to the use of a north skylight quality of illumination as a standard under which to match colors; likewise, much has been said regarding noon sunlight and average daylight. The color of daylight, including all of its variable colors with time of day and year, can be closely matched by artificial illumination employing suitable absorption screens. It would be presumptuous to say that any one color quality in the range available was best for inspection purposes because—and in spite of theoretical consideration—much depends upon the individual preferences of the inspectors as well as the character of the materials and colors being inspected.

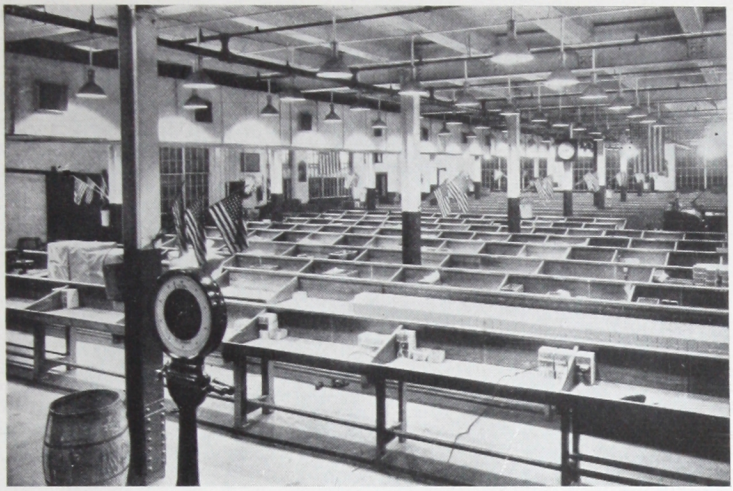


FIG. 1—The inspection of lamp bases is carried on under 75 foot-candles of illumination produced by spun aluminum reflectors spaced on 5-ft. centers, 8 ft. above the benches and equipped with 100-watt lamps.

FIG. 2—Large lighting units of low brightness in polished-plate manufacturing plant

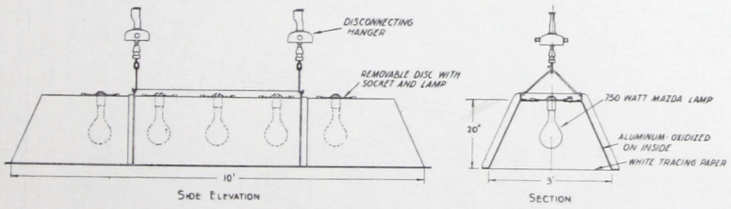


Fig. 3— Design of lighting units used in installation, Fig. 3

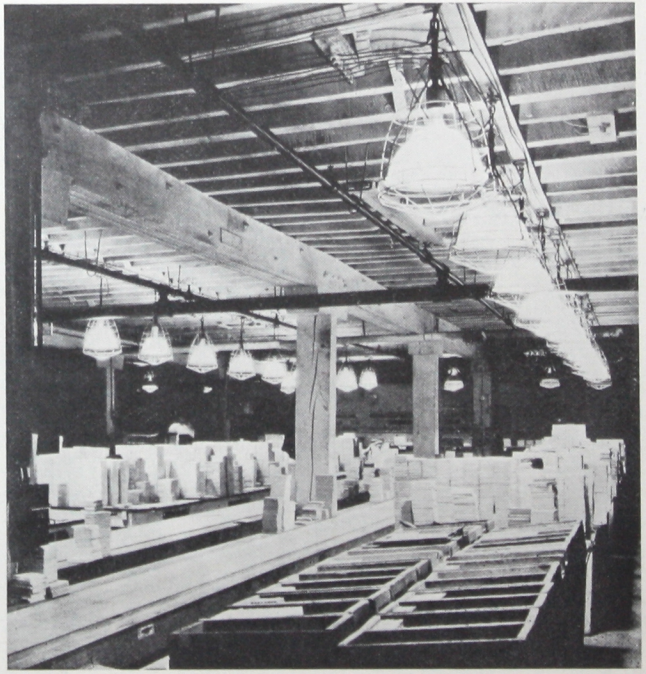


FIG. 4.—(Left) Application of high intensity lighting, well-diffused and directed to permit the delicate adjustment and inspection of relays.

FIG. 5—(Right) A group lighting system for the grading and matching of tile which is used for walls and floors. Prismatic reflectors are located on 4-ft. centers over grading tables and each is equipped with a 500-watt Mazda daylight lamp. An intensity of approximately 150 foot-candles of illumination is obtained.

In the application of spectral quality of light, there appears to be two very definite problems:

(1) The matching and duplication of colors or tints with that of an established standard on a production basis in the factory.
(2) The determination and selection of colors for materials that are to be used under lighting conditions unlike those under which they are produced.

For the first problem, whatever the spectral quality of illumination —daylight lamps, noon sunlight, or north skylight—is used for the inspection of colors on a production basis, one important element is the constancy of intensity and quality of that source. Under a constant quality and quantity, very uniform results of inspection can be expected after the inspectors have established their criteria of judgment. This is usually satisfactory for production and routine processes.

A more difficult problem would obtain if a color match throughout the spectrum were required between two materials. Taylor in the discussion of his paper[2] pointed out that where such a match is to be made, it is not always sufficient to make a color match under one source of light. Rather, it would be desirable to supplement color matches under artificial or natural daylight, with similar matches under light sources producing spectra of a different type. If the color match continues to exist under these two sources, it would be safe to say that the two objects were matched throughout the spectrum.

The second problem, that of appearance, applies to materials which are manufactured, purchased, or inspected under one color of illumination and which may be used under illumination of a different color and intensity. Regardless of the quality of lighting used for color matching the objects on a production basis, some thought should be given to the intensity and color of light under which judgment is passed as to their color effectiveness in service. Dress materials selected for brilliancy in natural daylight may lose that brilliance under the artificial light of the ballroom; automobile colors selected under ordinary artificial light may appear quite different on the road at noon.

The color-correcting lighting system can be obtained either by means of a general or group system of spacing, or by local units. Any of the several qualities of artificial daylighting can be applied in a general, or a group system but, because of the high absorption of light

[2] *Trans. I. E. S.*, Vol. XXV, p. 154.

necessary for duplicating north skylight quality, the more economical plan is to employ daylight lamps and noon sunlight equipments for general and group lighting, and to use the north skylighting equipments for local applications over relatively small areas.

For any given intensity of illumination, more wattage must be expended when using color-correcting equipments than with those having no color correction. Based on laboratory tests of commercial equipments, Table I gives the wattage multiplication factors necessary to obtain equal intensities with color-correcting equipments as compared with that required for an unmodified quality of illumination.

TABLE I—MULTIPLICATION FACTORS FOR THE WATTAGE NECESSARY TO OBTAIN EQUAL INTENSITIES OF ILLUMINATION WITH COLOR-CORRECTING EQUIPMENTS —BASED ON THE WATTAGE OF CLEAR LAMPS IN STANDARD REFLECTORS

Clear Lamp in Reflector, No Color Correction	1
Daylight Lamps, Standard Reflecting Equipment	1.5–2
Reflectors with Noon Sunlight Globes	3–4
Reflectors with North Skylight Plates	6–8

The places for color-corrected lighting are many, typical of which are: dye houses, and plants weaving color textiles; tile, paper, and paint factories; and commercial establishments where the materials matched, purchased, or graded should have the same appearance as under daylight conditions. Fig. 6 illustrates another important application of color-corrected light in a printing plant.

(3) Direction of Light—Luminaire Position:

Surface flaws; irregularities in surface shape; and small flaws such as pits, scratches, and cracks in materials are usually seen most easily by lighting which controls the direction of the light beam or the location of the source.

Small flaws on matte and non-specular surfaces are shown by the shadows cast from a beam of light striking the surface obliquely. The shadows may also be accentuated by the high-lights produced on the rounded edges of the irregularities nearest the light source. Many standard systems of lighting not particularly designed for this type of inspection produce these effects unintentionally because of the position of the work with respect to, or the nearness to, a light source in the work area. In general, the best lighting conditions for seeing small surface flaws on non-polished materials are produced by a

FIG. 6—Five-hundred watt noon sunlight units on 10-ft. by 10 ft. spacing provide a general illumination of 18 foot-candles of sunlight quality. Ninety foot-candles of north skylight quality illumination is obtained on the press receiving boards and make-up tables from north skylight units.

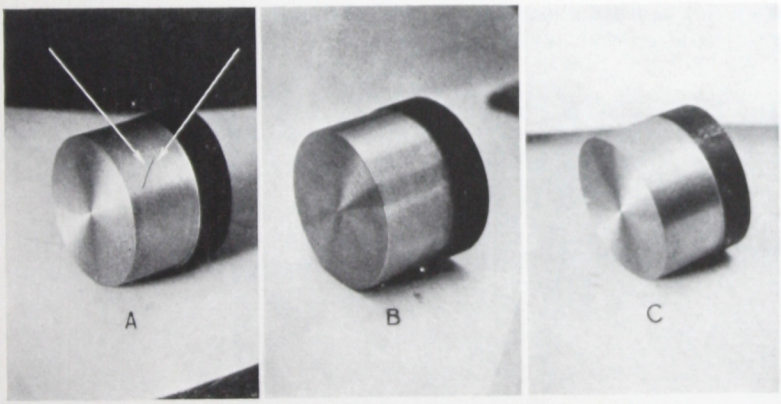


FIG. 7(a)—The diagonal scratch on the cylinder is revealed under lighting directed to cast a slight shadow without specular reflection toward the eyes.

(b)—Because of the lack of shadows, this defect cannot be readily seen under diffuse illumination.

(c)—When reflected glare is present flaws may be concealed.

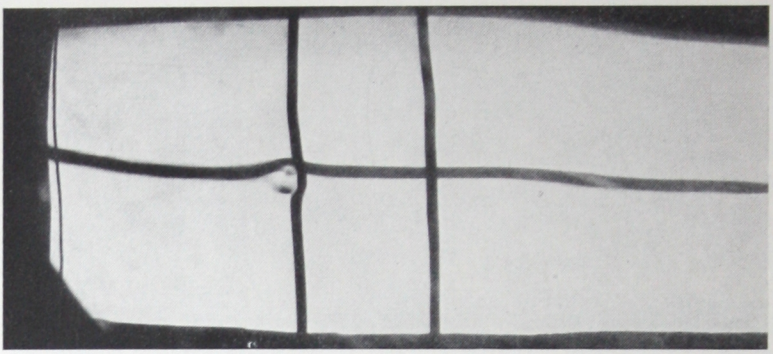


FIG. 8—Whorls or distortions in the reflected black strip help to locate the small dents and dings in polished surfaces.

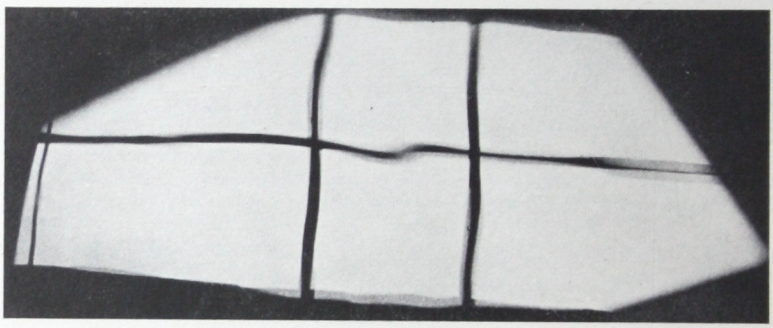


FIG. 9—Irregularities in contour, such as may occur in any flat glossy surface, can be detected by the wavy appearance of the black strip reflected in it.

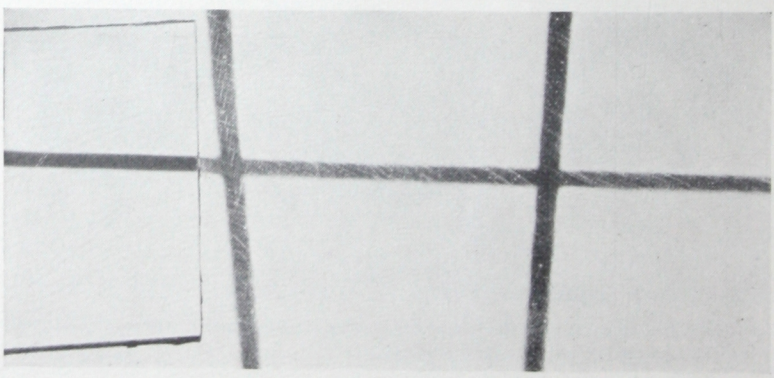


FIG. 10—A comparison of the reflected strip in the perfect mirrored glass surface at the left, with that in an imperfect surface which contains scratches and polishing marks.

luminaire with little diffusion, which is properly positioned to cast the shadows and high-lights. If the material is at all polished the light source should be positioned—probably to the right or left of the line of vision—to relieve the inspectors from any specular reflection which would be uncomfortable and which might actually conceal small flaws. Fig. 7 shows photographs of some of these effects on a small machined iron cylinder.

Another application that requires careful positioning and control of the reflection of the light source is for the inspection of highly polished surfaces for small flaws and irregularities. Here the reflected image of the light source itself is taken advantage of. The luminaire should be located so that its reflection can be seen in the work and of a size large enough to cover the area being inspected. Its brightness must be low so that it is neither uncomfortable nor conceals the flaws to be seen. Small specular areas can utilize brighter sources than large ones as suggested in a preceding paragraph.

The inspection of large polished or glossy surfaces such as chromium, aluminum, tin, glass, tile, paper, celluloid, etc., for surface imperfections is usually facilitated by looking at the images of light and dark bands reflected in them. These imperfections can be detected in the following manner:

1. Dents, dings, seeds, etc., can be located by whorls or distortions in the bands (Fig. 8).
2. Irregularities in contour, Fig. 9, are revealed by changes in curvature of the bands.

It is especially easy to find such imperfections when there is a movement of the line or band across the surface such as might be produced by a movement of either the piece being inspected, or the inspector's head. Scratch marks, and flaws in the grinding and polishing of the metals preparatory to plating, Fig. 10, show up as small hair-line distortions or waviness in the edges of the reflected bands.

A practical application of these principles is illustrated in Fig. 11 which shows the body finish inspection section of the conveyor line in a large automobile plant. Because of the position and location of the surfaces to be inspected, it is necessary to place light sources at the floor in addition to those at the ceiling.

Translucent materials, such as glass, paper, and celluloid, can be inspected by both reflected and transmitted light. However, the actual lighting necessary will depend upon the limits within which the

product must check with the standard set for some specific purpose. For example, ordinary window or sheet glass does not demand the thoroughness of inspection necessary for plate glass; the former is adequately inspected by reflected light, while the latter demands a more careful inspection by placing the glass plate between the inspector's eyes and a suitable light source.

In a large sheet-glass manufacturing plant the glass was inspected and cut into smaller sheets in front of windows under natural daylight. The glass which was in sheets approximately 40 inches x 80 inches in size, was placed in a horizontal position on a table with a black felt top. The inspector's position was such that he could get the reflected image, in the glass, of the sky through the window. The black felt background provided a constant background against which the glass was graded and at the same time practically eliminated any light that might otherwise be reflected back through the glass, or appear to the inspector as transmitted light which would be annoying to him rather than helpful.

Inasmuch as natural daylight was depended upon to provide suitable lighting, much time was lost in this plant during the early morning and late afternoon hours on dark days; even during the hours when the lighting appeared adequate, it was continually changing in quantity. As a result of this variation in light, the records of the plant showed that on the darker overcast days a higher percentage of their product was actually placed in the "A" quality grade because certain defects were not readily detected under the lower illumination.

The solution of the problem would be to use a large artificial light source which, if desired, could be made of the same size and shape as the part of the window through which natural daylight is used. Such an artificial source would consist of a large box about 3 ft. wide and 4 to 6 ft. long, with a sufficient depth to permit a fairly uniform distribution of light of low brightness on a milk white glass, or paper, front. Experimental work with the inspectors indicated some differences of opinion as to just how bright the diffusing glass or paper front should be but, in general, it was thought that an agreement could readily be reached and thereby standardized on a uniform source under which to inspect sheet glass. With equipment such as this, natural daylight would not be required and, as a matter of fact, its presence would be objectionable. The elimination of daylight did not meet with favor in the particular plant above referred to, but experiments were being made with artificial windows which were to be hung in the present

window casings and swung into place during the hours when daylight was inadequate. With this arrangement daylight lamps would be used in the equipment so that the artificial illumination would more closely approximate daylight in color. No information is available as yet regarding the results of this experimental work, but it has promise of being a great improvement over the past practice.

(4) Diffusion:

While lighting engineers have long realized the value of diffusion in lighting and have put it to good use, it has been applied more because of its quality characteristics—protection to eyesight, the elimination of glare, and the softening of shadows—than because of its application in producing reflected images in polished metal surfaces.

It is especially difficult to see certain defects that appear in many polished or plated metal surfaces under good standard interior lighting, or even under good natural lighting, because the mirror-like surfaces which faithfully reflect every light source, difference of brightness in the interior, and images of walls, windows, and machines, conceal the flaws that must be seen. Some of the more important defects, such as those caused by inadequate plating, appear as very slight color differences.

Chromium, for example, is usually plated over nickel. The former has a blush tint; the latter a yellowish one. These color differences, which are almost undiscernible in newly plated pieces, would find little objection if those color differences remained unchanged. However, when the unprotected nickel tarnishes and the chromium does not, the color difference becomes very apparent. Again, when buffing pieces that are nickel-plated on brass, the wheel may cut through the plating on a corner, or high spot, to the brass base. Since newly buffed brass is almost as white in color as nickel, the spot which is cut through is hard to find and it is often weeks later that the brass darkens and shows the spot to a great disadvantage. To a lesser degree the same inspection problem occurs where nickel is plated on copper, or copper on iron.

The above difficulties are typical in the entire plating industry, and there are many unsatisfactory plating jobs being turned out today because the inspection is done under standard lighting conditions and without due respect for the difficulty of the visual task.

The best lighting for this job obtains under complete diffusion—diffusion such as would be obtained if the inspector could work on the

inside of a huge opal glass ball lighted from the outside. While that is impracticable, an approach to that ideal can be made by some of the methods outlined by Ketch[3] several years ago.

The experimental method described in his paper consisted of a half cone of diffusing material, built into a box containing lamps to light the cone from the outside. The inspection was done inside of the cone. Recent applications of this same lighting principle have been made in larger booths and tunnels, such as is illustrated in Fig. 12, in which one or more men carry on inspection work on polished and plated metals. The objective in lighting effect is common in the design of all: complete diffusion, as few differences of brightness as possible, and no high brightness images to be reflected in the surface. Both unmodified and daylight quality sources of light have been used satisfactorily; however, the preference of most inspectors seems to be for an illumination that approaches daylight in color quality.

While the detection of color differences is of first importance in the inspection of plated metal parts, there are other surface imperfections of a different character such as pits, blisters and wheel marks that may be of such a magnitude as to be objectionable. Highly diffuse illumination as used in the above-mentioned booths and tunnels is not the best for detecting these imperfections, and, furthermore, as previously discussed, complete diffusion tends to conceal rather than reveal them. This difficulty can, however, be readily overcome so that the same booth can be used for the general inspection and detection of flaws of every character by adding black bands to certain areas in the background of the booth. Also where there are straight lines dividing differences of brightness, such as on the ceiling of the booth shown in Fig. 12, these lines assist in the detection of such surface imperfections.

(5) *Projection and Magnification*

In the laboratory and elsewhere one often finds work being done on such small objects that careful inspection can only be made by magnifying them. The watch-repair man has his eye-piece; the physicist his microscope, and the index of magnification necessary depends not alone upon the initial size of the object, but also upon the amount of light available to assist vision. Many microscopes have small light sources built into them to provide sufficient light of the proper direc-

[3] *I. E. S. Trans.*, XXIII, p. 639.

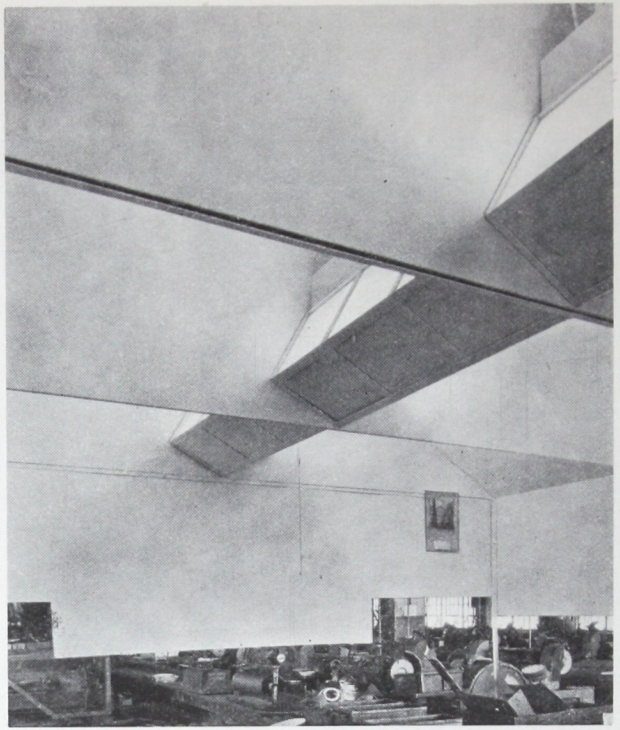
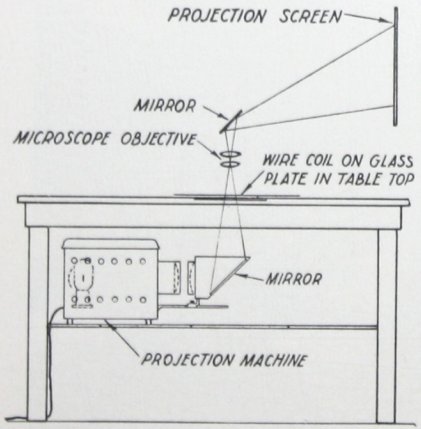
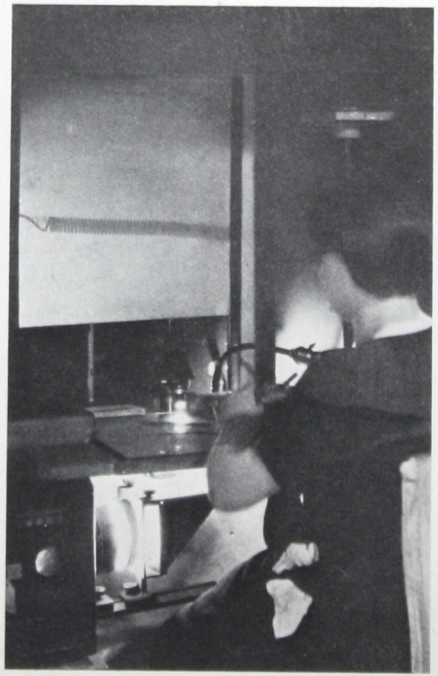


FIG. 11—(Left) Reflected images of the trough-shaped lighting units at the floor reveal dents, dings, and irregularities in contour and finish in the sides of automobile bodies.

FIG. 12—(Right) Inspection booth 15 ft. square designed to obtain highly diffused daylight quality illumination for the detection of color differences in chromium-plated parts.





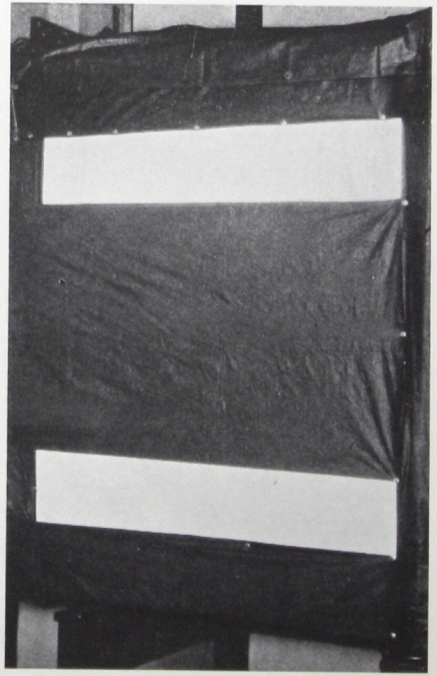


FIG. 13—(Left) Projection machine and microscope objective lens arrangement as used in the inspection of lamp-filament coils
FIG. 14—(Center) Use of the equipment, shown in Fig. 13, for the inspection of small wire coils
FIG. 15—(Right) Experimental luminous box as used for the inspection of plate glass

tion and spectral quality. In general, these instruments are for laboratory use where detailed studies are made, rather than for factory inspection work where it is desired to detect only one or two defects of a certain definite character. The actual design of magnifying equipment adaptable to factory work will depend upon the kind of inspection necessary. For example, in a lamp factory the winding machines for coiling the fine hair-like tungsten filament wire are each equipped with a focusing type microscope to make it possible to see the wire as it is wound on the mandrel. On the other hand, when the individual coils are inspected on a production basis for irregularities in shape, spacing, size, and freedom from foreign substances, it would be a laborious job to use an ordinary miscroscope. This inspection work is greatly simplified by projecting the magnified image of the wire coil onto a screen. The assembly of a projection equipment and objective lens system is shown in Fig. 13. An actual installation of the equipment is shown in Fig. 14. When using this equipment a group of wire coils is placed on the glass plate, and each one individually slid across the plate through the beam of light. Because the projected silhouette is many times the actual size of the coil, any irregular shapes or improper spacings can readily be detected. Similar equipments can be employed for the inspection of production machine parts where accuracy in size and shape is essential. Typical of this application are the machines now in common use for projecting an enlarged silhouette of a gear tooth onto a profile chart, and for watching the meshing of these production gears with a perfectly cut standard.

(6) *Refraction*

The principle of refraction is applied particularly to the inspection of clear transmitting substances such as plate glass and certain other glass products. This application is very similar to that used for the inspection of surface flaws and aberrations in polished surfaces. The same type of light source—dark strips against low brightness backgrounds, or rectangular shaped box luminaires located at strategic points—can be used. The dark strips, or lines dividing the light and dark areas of the boxes are distorted by refraction through the glass, and thereby disclose the location of the flaw. The best condition obtains when either the head of the inspector, or the material being inspected, is moved.

The results obtained from a recent experience in the inspection department of a large plate-glass factory will illustrate the practical application of this principle. It was found that the accuracy necessary for inspecting polished plate glass is a great deal more precise than that for sheet glass. Certain undesirable defects are readily observed under reflected light, while others are detected more quickly by refraction when using a lighted background.

In the early stages of our experimental work in the plate-glass factory, it was recognized that we must have an experienced glass inspector to guide the work and to draw the conclusions. Arrangements were made, therefore, with the manufacturer to have their chief inspector spend several days in our lighting laboratory where we could set up, and he could compare, different lighting schemes while inspecting typical plates of glass. Assisted by the practical assistance given by the inspectors, and by earlier experiments in the plant, the laboratory experiments confirmed the fact that the most difficult flaws to discover could be most readily found by refraction of the light transmitted through the glass rather than by the light reflected from the surface, or by a combination of the two. Also, since no objectionable flaws were made unobservable by transmitted light, this was the basis on which the experimental work was continued. To carry out the experiment a box 4 ft. square having a white diffusing glass cover plate was constructed. Lamps of any desired size could be placed behind the glass to provide a uniformly lighted panel of various brightnesses. With a sample glass plate in position, this light source was unsatisfactory for inspection, except at those sections where the glass plate was viewed in a line with the edge of the box. This indicated that it was necessary to have a combination of light and dark areas against which the inspector could alternately view the glass plate.

The next problem then became one of determining the proper ratio between the size, and shape, of the light and dark spaces. Fig. 15 shows black strips of cloth across the front of the luminous box. By rearranging these cloth strips various combinations were readily obtained. Also, the sizes of the lamps in the box were varied to provide a range in brightnesses. From this experimental work the following conclusions were drawn regarding a lighting equipment suitable to permit the proper general inspection of plate glass:

1. The glass should be viewed against a combination of light and dark areas.
2. The light source must be comparatively low in brightness—not over 4 candles per square inch.

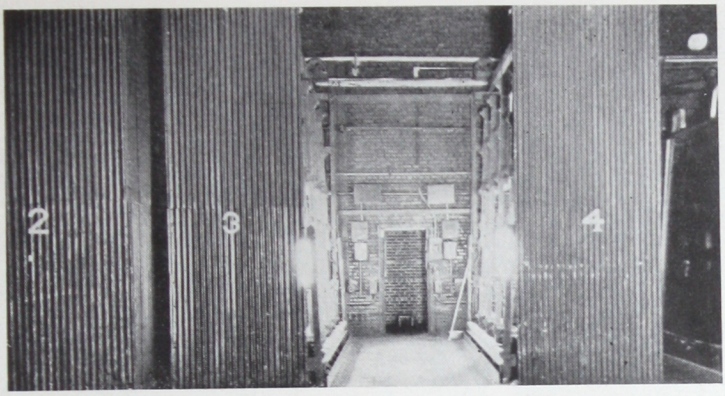


FIG. 16—Booth for the inspection of plate glass

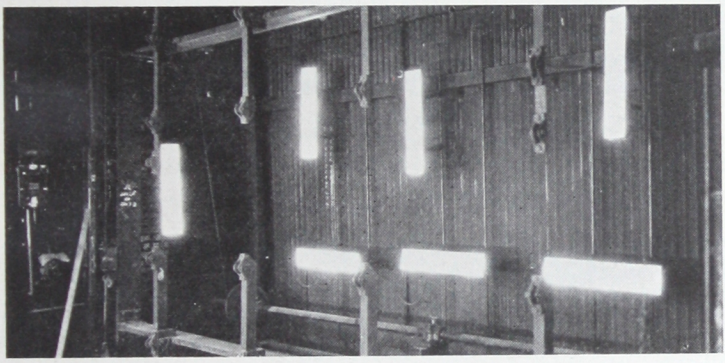


FIG. 17—Arrangement of trough reflectors on wall of plate glass inspection booth

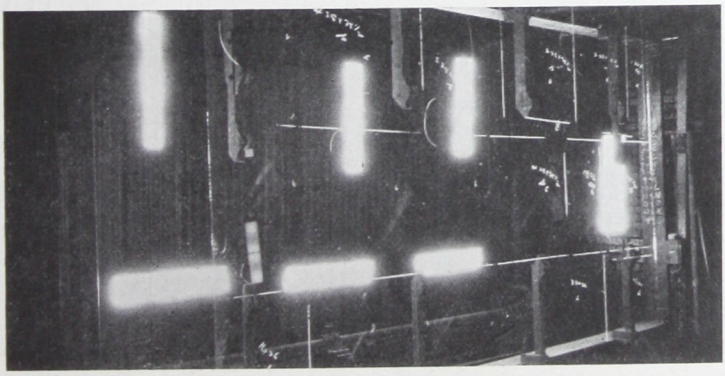


FIG. 18—Booth showing position of plate glass with respect to the lighting units 6 ft. behind

Fig. 19—Re-inspection of the larger plates of glass received from the initial inspection and cutting (Fig. 18).

FIG. 20—Detailed inspection of plate glass for mirrors

3. The light source should preferably be rectangular in shape with a width of 5 inches to 6 inches and a length of 24 inches to 30 inches. With a unit of this size the width of the dark spaces between the units should be of the order of 2 feet to 3 feet.

In order to eliminate all extraneous light and recognizing the practical problems involved in the factory, the plate-glass company had already decided to construct inspection booths as illustrated in Fig. 16. The booth is 19 feet wide and 18 feet deep; the aisle for the inspector is 7 feet wide. This illustration shows the supports on both the right and left for the large glass plates. Fig. 17 shows the right side of the booth, and illustrates the recommended arrangement of lighting units on the wall approximately 6 feet behind the support for the glass plate. Eight trough-shaped units are employed, each one being 30 inches long and equipped with four 75-watt Mazda lamps. Fig. 18 is a view of the left side of the booth which shows a glass plate in place which has been inspected and marked for cutting. The supporting framework for the glass plate can be raised or lowered to bring the glass area between the eyes of the inspector and one or more of the lighting units. Figs. 19 and 20 show other views in the plate glass factory where the special trough-type units are used for more careful and detailed inspection of the glass plates.

(7) Internal Reflection

Some of the flaws common in transparent substances are bubbles and fire cracks which can be easily seen by the light reflected from the flaw itself. The exterior of a bubble in a glass jar, for example, becomes a convex mirror which will reflect an image of a fairly sharp, and bright, light source to the eye. Fire cracks are hard to see because of their small size; the two sides of the crack, however, act as mirrors which reflect an image of the light source, especially if the source is of high brilliancy, such as a clear 200-watt lamp in a deep-bowl reflector, and located close to the object. Here again the object being inspected should be moved or rotated while the inspector watches for the bright reflections that disclose the flaw.

A modification of the above principle is one where objects for some reason or other are viewed while under water. One usually has difficulty in seeing objects under water because of the reflections of the light source in the water surface, hence for problems of this nature it is best to locate the light sources beneath the surface of the water in order that disturbing reflections may be eliminated. It is well known

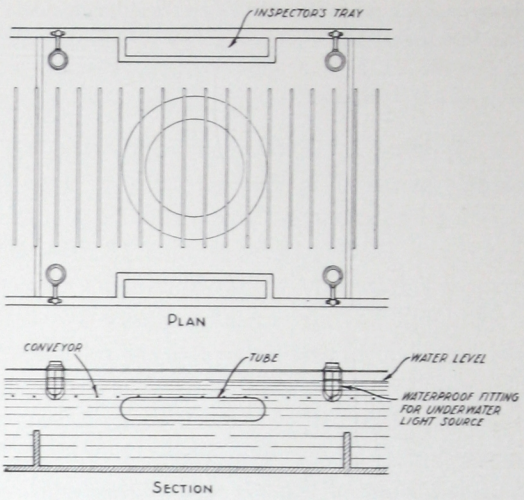


FIG. 21— Plan of underwater lighting in the inner tube inspection tanks of a rubber tire manufacturer

that the bottom of a swimming pool can be viewed more readily when under-water lighting equipment is employed than when overhead units are used—likewise with other objects.

An example of this type of lighting is found in an automobile tire manufacturing plant where inner tubes are inspected for air leaks by passing them, when partly inflated, through a tank of water. The air bubbles are immediately detected by reflected light when the lighting equipment is placed under the water. The sketch, Fig. 21, shows the arrangement of lamps in the tank with respect to an inner tube and the water level. The authors wish to give credit to Ward Harrison for initiating and developing this idea.

(8) *Polarization*

Strains in glass caused by poor annealing are disclosed by looking through the area under question at a source of polarized light. The strained areas appear as slight color fringes in the glass.

(9) *Ultraviolet Radiation*

The application of ultraviolet radiation for inspection work is, as yet, relatively undeveloped, although its fluorescent effect upon certain chemical compounds and organic substances is well known.

Commercial ultraviolet equipments, rated as strong sources, can

be modified to produce fairly pure ultraviolet radiation with little visible light when equipped with suitable screens. In an otherwise dark room, many erasures and changes in signatures and figures, and changes and forgeries in legal documents can be detected by a source of radiation of this nature.

The distribution, intensity, and uniformity of ultraviolet sources can be controlled and are, therefore, more satisfactory than natural sunlight for testing the permanency of dyes, paints, inks, oils, resins, and varnishes. Experiments tend to indicate that other practical uses will be made of ultraviolet radiation such as the detection of small amounts of ultraviolet-sensitive substances in organic mixtures, and uses made of the photochemical, fluorescent, and phosphorescent effects upon certain compounds.

(*10*) *Photoelectric Tube and Photronic Cell*

With the rapid development of photoelectric tubes on a commercial basis, and the recent introduction of the photronic cell, we now have at our command the means for the automatic inspection and grading of products by their light output, reflection factor, or transmission factor.

The photoelectric tube operates by light which, falling on a sensitized cathode, causes an electron emission that allows a current to flow. This current is proportional to the light flux but, because the current is of a low order, amplification is usually necessary if it is to be large enough for practical use.

There are limits to both their sensitivity and time for operation. W. R. King[4] states that the a.c. photoelectric relay operates on light changes of the order of 40 to 50 per cent, and may be successfully operated with light intensities as low as 10 foot-candles; that is, with an illumination of 10 foot-candles the contactor of a relay system is open, but if the light is decreased to five foot-candles the contactor will close. The d.c. photoelectric relay may be operated by an illumination change of about two foot-candles, this value remaining practically constant between five and twenty foot-candles.

The photronic cell such as is now used with a recently developed illumination meter also has possibilities for inspection purposes since the cells can be used in groups to build up higher current values.

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[4] International Electrical Congress, Paris, 1932.